DOCUMENT RESUME

ED 207 866 SE 035 818

TITLE	NASA's Role in Aeronautics: A Workshop. Volume VI - Aeronautical Research.
INSTITUTION	National Academy of Sciences - National Research Council, Washington, D.C. Assembly of Engineering.
SPONS AGENCY	National Aeronautics and Space Administration, Washington, D.C.
PUB DATE	81
CONTRACT	NASA-NASW-2342
NOTE	26p.; For related documents, see SE 035 814-819 and SE 035 731.
AVAILABLE FROM	Aeronautics and Space Engineering Board, National Research Council, 2101 Constitution Ave., N.W., Washington, DC 20418 (no price quoted).
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	*Aerospace Education; *Aerospace Industry; *Aviation Technology; Engineering Education; Higher Education; Metallurgy; Research Needs; Science Education; *Scientific Research; Technology; *Workshops
IDENTIFIERS	*Aeronautical Research; *Aviation Education

ABSTRACT

The central task of a 1980 workshop on the role of the National Aeronautics and Space Administration (NASA) in aeronautics was to examine the relationship of NASA's research capabilities to the state of U.S. aviation and to make recommendations about NASA's future role in aeronautics. Following a brief introduction, the Overview Panel on Aeronautical Research considered aeronautical research related to: (1) Turbulence; (2) Noise; (3) Supercritical Aerodynamics; (4) Computational Aerodynamics; (5) Fuels; (6) High Temperature Materials; (7) Composite Materials; (8) Single Crystal Components; (9) Powder Metallurgy; (10) Flight Controls; (11) NASA Structural Analysis (NASTRAN) Program; (12) Lubricants; and (13) Composites. Conclusions, recommendations, and definitions of roles and disciplines in an appendix are also included. (Author/DS)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

NRC NAS NAE IOM

ED207866

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
X This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

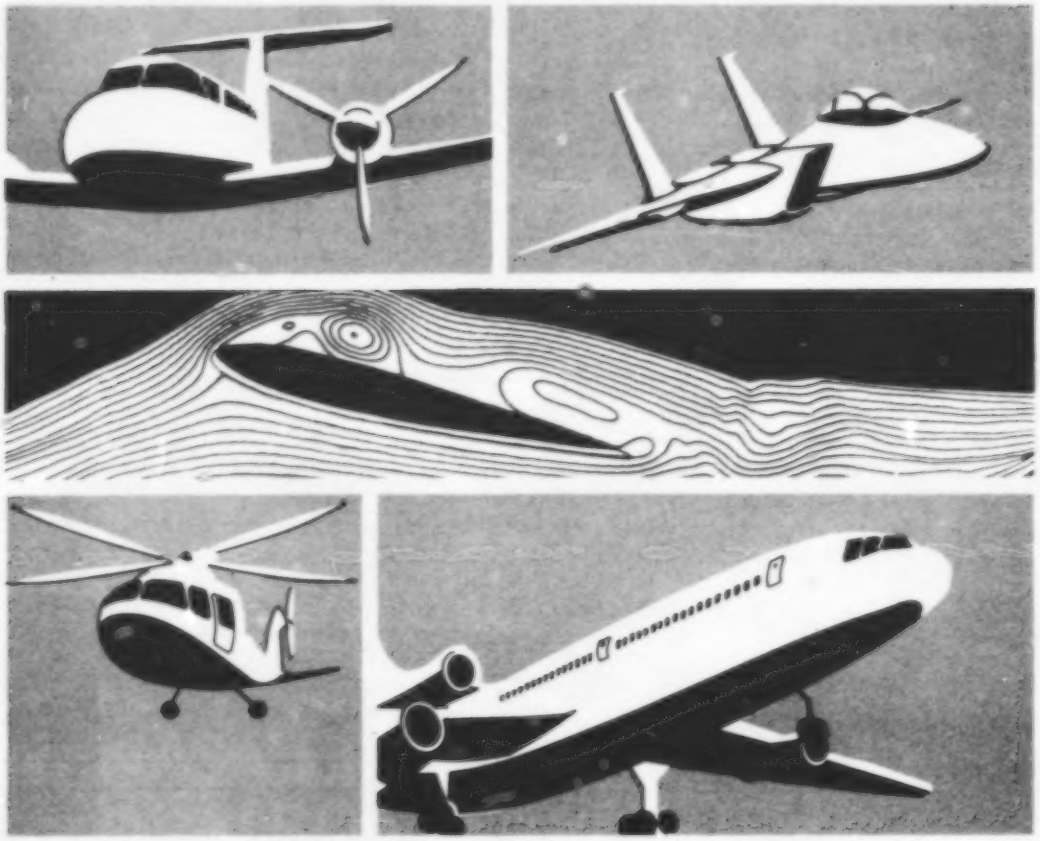
NASA'S ROLE IN AERONAUTICS: A Workshop

Volume VI Aeronautical Research

SE 035 818

NASA'S ROLE IN AERONAUTICS: A Workshop

Volume VI Aeronautical Research



Report to the Workshop by the Overview Panel
Aeronautics and Space Engineering Board
Assembly of Engineering
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1981

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Research Council was established by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and of advising the federal government. The Council operates in accordance with general policies determined by the Academy under the authority of its congressional charter of 1863, which establishes the Academy as a private, nonprofit, self-governing membership corporation. The Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in the conduct of their services to the government, the public, and the scientific and engineering communities. It is administered jointly by both Academies and the Institute of Medicine. The National Academy of Engineering and the Institute of Medicine were established in 1964 and 1970, respectively, under the charter of the National Academy of Sciences.

This report and the study on which it is based were supported by Contract No. NASW-2342 between the National Aeronautics and Space Administration and the National Academy of Sciences.

Copies of this publication are available from:

Aeronautics and Space Engineering Board
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

WORKSHOP ON
THE ROLE OF NASA IN AERONAUTICS

OVERVIEW PANEL

A Richard Seebass - Co-Chairman
Department of Aerospace and
Mechanical Engineering
University of Arizona

R. Dixon Speas - Co-Chairman
President
Aviation Consulting Incorporated

Neal Blake
Deputy Associate Administrator
for Engineering and Development
Federal Aviation Administration

Secor D. Browne
President
Secor Browne Associates

Walter P. Frey
Manager, Technical Service
Aviation Department
Mobil Oil Corporation

James E. Gorham
SRI International

Klaus P. Heiss
President
ECON, Inc.

Milton J. Kittler
Retired President and
Chief Executive Officer
Holley Carburetor Company

James J. Kramer
Manager, Strategic Planning and
Development Operation
Aircraft Engine Group
General Electric Company

James N. Lew
Retired Senior Vice President,
Engineering
Beech Aircraft Corporation

Arthur D. Lewis
President
American Bus Association

Hans W. Liepman
Director, Graduate Aeronautical
Laboratories
California Institute of
Technology

Richard J. Linn
Director, Technological
Development
American Airlines

Robert G. Loewy
Institute Professor
Rensselear Polytechnic
Institute

Courtland D. Perkins
President
National Academy of Engineering

Clifton F. von Kann
Retired Senior Vice President
Operations and Airports
Air Transport Association of
America

PREFACE

Aeronautics is changing in many significant respects. The implications of this are so far-reaching as to call into question the future position of the United States in world aviation.

The magnitude of this question, with its possible consequences for the nation's economy and security, led the National Aeronautics and Space Administration (NASA) to seek an independent evaluation from the Aeronautics and Space Engineering Board (ASEB) of the National Research Council's Assembly of Engineering. Specifically, the ASEB was asked to assess the nature and implications of the current state of U.S. aviation in a world setting and their significance for NASA's role in the nation's aeronautical future.

The ASEB responded by convening a workshop July 27 through August 2, 1980, at the National Academy of Sciences' Woods Hole Study Center. The workshop was structured into four panels covering military aviation, transport aircraft, general aviation, and rotorcraft. In addition, an overview panel was formed to consider NASA's role in research as well as its relationships with other elements of the aeronautics community.

The central task of the workshop was to examine the relationship of NASA's aeronautical research capabilities to the state of U.S. aviation and to make recommendations about NASA's future roles in aeronautics.

NASA and its predecessor, the National Advisory Committee for Aeronautics (NACA), traditionally have maintained a cooperative relationship with the aeronautical industry, with other government agencies concerned with aircraft operations and regulations, and with the academic community engaged in aerospace research. This triumvirate was taken into account in planning the workshop and selecting the participants. Thus, representatives from each part of the aeronautical community were invited, and information on NASA's relationship with each was the subject of special presentations prior to the working sessions. Representation from industry was predominant because industry's relationship with NASA is considered to be a key element in examining the present and future roles of NASA.

The members of the workshop panels represented, in total expertise and experience, all of the important sectors of aeronautics: military aircraft and missiles; commercial air transports; general aviation;

rotorcraft; university and private research; airline operations; and government regulatory agencies. In addition, the participants also included representatives of other industries--notably, automotive, electronics, and steel. Including the speakers and other nonpanel members, close to 80 individuals participated.

The participants were asked to address the issue of NASA's role in the context of a wider discussion concerning: the status and dimensions of U.S. aeronautics; the key aeronautical problems and opportunities that are likely to be amenable to research and technology development; the historical evolution and accomplishments of NASA in aeronautical research and technology development; and possible alternatives to NASA. Each of these subjects is discussed thoroughly in separate panel reports.

The report of the workshop consists of seven volumes:

I -- Summary

II -- Report of the Panel on Military Aviation

III -- Report of the Panel on Transport Aircraft

IV -- Report of the Panel on General Aviation

V -- Report of the Panel on Rotorcraft

VI -- Report of the Overview Panel on Aeronautical Research

VII -- Background Papers--The Outlook for Aeronautics and Relevant Areas

In order to help focus the discussion, NASA officials developed and provided a concise set of definitions of eight possible roles for NASA: National Facilities and Expertise; Research; Generic Technology Evolution; Vehicle Class Technology Evolution; Technology Demonstration; Technology Validation; Prototype Development; and, Operations Feasibility. Because some of these roles differ, depending on the aeronautical discipline involved, the roles are assessed within six principal aeronautical disciplines: aerodynamics, structures and materials, propulsion, electronics and avionics, vehicle operations, and human engineering. Definitions of these roles and disciplines are contained in Appendix A. The matching of the roles and disciplines is treated in Volumes II-VI and summarized in Section II of Volume I.

The workshop participants were extensively briefed by officials from NASA, the Department of Defense (DOD), and the Federal Aviation Administration (FAA), by leaders from the aviation manufacturing and operating industries, and by a member of Congress. The briefings are to be found in Volume VII.

Each panel separately considered the national benefits produced within the dimensions of its sector and the relative state of the sector's world position; each considered the evolution of NASA's role,

as well as a rationale for NASA's aeronautical support of its sector; and, finally, each panel produced sector-oriented conclusions and recommendations for NASA's roles for the future. Although there are obvious overlaps, the similarities and differences in each of the panels' findings are preserved in the separate reports of the sector-oriented panels, Volumes II-V.

This document, Volume VI, contains a dissertation on aeronautical research that was prepared by the Overview Panel.

CONTENTS

INTRODUCTION 1

SUCCESSES AND CHALLENGES 3

- Turbulence
- Noise
- Supercritical Aerodynamics
- Computational Aerodynamics
- Fuels
- High Temperature Materials
- Composite Materials
- Single Crystal Components
- Powder Metallurgy
- Flight Controls

SPIN-OFFS 11

- NASTRAN
- Lubricants
- Composites

CONCLUSIONS AND RECOMMENDATIONS 13

REFERENCES 15

APPENDIX A: DEFINITIONS OF ROLES AND DISCIPLINES 17

INTRODUCTION

Man's ability to fly, and to do so at high speeds in comfort and safety, is a consequence of many factors. Of these, the most fundamental is research. Manned flight was successful in this country because the Wright brothers understood the value of research. Fortunately, in the United States the need for government involvement in aeronautical research was recognized early with the creation of the National Advisory Committee for Aeronautics (NACA) in 1915. NASA was formed in 1958 to broaden the mission of NACA to include the exploration of space.

NASA currently contributes to aeronautical technology in many ways. These include providing new knowledge in the flight sciences (Research), pursuing this knowledge through its application to aircraft in general (Generic Technology Evolution), seeing that the technology is applied to advance the development of specific vehicle classes (Vehicle Class Technology Evolution), demonstrating its effectiveness (Technology Demonstration), and validating its technological readiness for service use (Technology Validation). While each aspect of its aeronautical technology program has been important to the current preeminence of the United States in aeronautics, the most essential contributions of NASA derive from its research.

Other governmental agencies also make contributions to aeronautical research, but their roles are minor by contrast with NASA. The National Science Foundation, for example, has a mandate to ensure progress in understanding and knowledge in all areas in which no clearly established government responsibility exists. Other government agencies conduct basic research in disciplines fundamental to their mission. For the Department of Defense (DOD), this includes aeronautics. However, only within certain relatively small areas does DOD's needs for basic research overlap with those of NASA.

Research germane to aeronautics is carried out by DOD laboratories that have the appropriate capabilities in expertise and facilities. Very often, NASA carries out the aeronautical research needed to support a DOD program or the program of another agency. Thus, there is a constantly evolving, particularly important core area of generic research in aeronautics for which NASA, and NASA alone, has the responsibility.

Role of Research

It is a general and intuitive observation that technological innovation brings many benefits to society. Only recently has this perception by scientists and engineers been investigated to quantify the benefits to society of selected innovations.[1] The general conclusion from such studies is that there are marked societal benefits from most innovations and that the quantified rate of return to society is quite large. It is also observed that this rate of return is much higher for society than it is for the innovator. Indeed, it is further noted that some innovations with great societal benefit have provided little return to the innovators.[2]

SUCCESSES AND CHALLENGES

The quest for a fundamental understanding of the basic phenomena underlying a discipline and the search for new ideas that derive from this understanding are what is meant by research. The importance of research in general is documented in the data presented in Science Indicators, 1976, a report prepared for the President by the National Science Board.[3] In this paper, Volume VI of NASA's Role in Aeronautics: A Workshop, the discussion is limited to an illustration of the role of research in advancing aeronautical technology. The purpose is to document the fundamental importance of such research and to suggest some future opportunities. To do this, a few selected examples are provided. It should be noted that research results in some of these examples were readily picked up by the industry, but others required extensive technology evolution and validation programs before being accepted by the private sector.

Turbulence

Aerodynamics is a discipline that occupies a very peculiar position in the physical sciences. The equations of motion for fluids have long been known, and it should be possible, in principle, to solve the equations numerically. This is not generally the case because the complexity of the equations defies the capabilities of existing computers. For most fluid flow problems of technical importance, the flow is turbulent. Despite the effort of some of the most celebrated minds of our time, turbulence is still incompletely understood.

Turbulence generally increases the diffusion or mixing of mass, momentum, and energy. The increased mixing can be detrimental or beneficial. Turbulence increases skin friction and hence increases drag on the aircraft's external surfaces; it also accelerates fuel-air mixing, thus accelerating combustion. Turbulence increases heat transfer, which can be good or bad depending on the aeronautical application. Thus, the understanding and control of turbulence is of crucial importance in aeronautics.

High performance aircraft and missiles can be built today on the basis of long, tedious, and often frustrating research on turbulent flows. Such research forms the foundation for our present but limited

understanding of turbulence, as well as the semi-empirical prediction and computational methods used today in aeronautics. The importance of the contributions of NACA, and later NASA, to this research base cannot be overestimated. Indeed, one of the most significant steps toward an understanding of turbulence, the clarification of boundary-layer instability, resulted from NACA-sponsored research.

Without turbulence research conducted in the past, progress in the control of jet noise would have been impossible. Similarly, research on the control of vortex wakes behind aircraft involves the same basic models. Difficult problems like these, which are both of fundamental interest and of long-term significance, require the active participation of an agency like NASA. That NASA can and does link fundamental research to design studies makes its contributions even more important.

Noise

Aircraft noise has become a significant environmental problem. During the decade of the 1950s, noise emitted from turbulent jet exhausts presented a completely new research issue. Today, the physics of the problem, aside from turbulence, is reasonably well understood. The most conspicuous feature of jet noise is that it is very dependent on the jet velocity. A doubling of exit velocity will result in a 250-fold increase in the acoustic power. Thus, reducing the exit velocity required to obtain a given thrust is the dominant means for reducing noise. This is achieved by efficient high-by-pass engines. Compressor and turbine noise are more conventional problems, and acoustic treatment of the engine ducts was, and is, being used to great advantage.

To date, many of the changes made in engine acoustic characteristics have been derived from NASA research. The changes have resulted in an overall reduction in commercial jet noise by nearly 30 perceived noise decibles (PNdB), when the first jets (707 and DC-8) are compared to present aircraft (B-747, L-1011 and DC-10). This required nearly a 1000-fold reduction in sound energy. Considering the difficulties of the problem, the reduction of jet noise constitutes an outstanding success.

Supercritical Aerodynamics

Commercial jet aircraft operate at high subsonic Mach numbers (aircraft speed divided by the speed of sound). At higher speeds travel time is shortened and aircraft use is increased. Turbojet engines, as a class, reduce fuel consumption because propulsive efficiency is nearly directly proportional to the Mach number. The overall aircraft efficiency is then directly proportional to the product of the Mach number times the lift-to-drag ratio. When the flight speed exceeds the speed of sound, the product decreases because the benefit of increased speed is more than offset by an increase in the drag caused by shock waves associated with the lift of the aircraft. At high subsonic speeds, there are local regions where the flow speed exceeds the speed of sound; this phenomenon is called supercritical flow. Research at universities in the mid-1950s showed that supercritical flows nearly always contain shock waves, and it was thought for some time that

flight at supercritical (but subsonic) Mach numbers would always be penalized by the drag associated with these shock waves. Not surprisingly, optimum performance is usually achieved when a weak shock wave is present.

Some ten years later, experimental studies at NASA and in Europe demonstrated that shock-free flows could be achieved, although this is clearly the exception rather than the rule. An effort was mounted to find families of wing sections that had otherwise desirable properties and were shock-free in supercritical flight. The collaboration between university researchers and the NASA staff who carried out parallel research in the wind tunnels at the Langley Research Center was especially important in the resolution of this problem.

The benefits of this research were first demonstrated by joint DOD-NASA flight test programs that validated the posited improvements using a modified T-2C and F-8 aircraft. The aviation industry has made rapid use of this technology.

The progress made, from the mathematical proof that shock-free supercritical flows rarely occur to the practical utilization of nearly shock-free flows in commercial and military aircraft, will result in a 5-10 percent improvement in aircraft fuel efficiency.

Computational Aerodynamics

In the early days of aeronautics, only wind tunnel tests provided the basic aerodynamic data required by industry for airframe and propeller design, as well as for airframe/engine integration. While the wind tunnel only approximated free flight conditions, the model was sufficiently accurate to allow for major improvements in aircraft performance through experimentation.

Today, a revolution is under way that promises to generate data accurate enough for the design of aircraft configurations in only hours, rather than the days or months required for wind tunnel tests. The revolution results from faster computers, decreased costs of logic circuitry and memory systems, and improved computer architecture, coupled with improved numerical methods and computational efficiency. In the last decade, the research literature on the computation of nonlinear aerodynamic flows has grown from a few annual papers published to fully half of the papers published in aerodynamics. This is not surprising. The development of the software that provides the algorithmic advances is difficult, and a massive effort is essential to attain the necessary software. Strikingly, the algorithmic advances continue at a pace that nearly matches the speed of development in computer memory size and circuit speed.

For many engineering design studies of aircraft, engine components, and rotors, a numerical simulation of the solution to a simple model of the governing equation will suffice--i.e., the Reynolds-averaged Navier-Stokes equations with closure using a simple turbulence model. This can be achieved with an increase by a factor of 100 in memory size and circuit speed over present day computers, coupled with a computer architecture that realizes these gains in system performance.

It is hard to predict the magnitude of the aerodynamic performance gains that will result from nonlinear aerodynamic designs. There are

many indications, however, that such designs will result in 10-15 percent increase in performance for simple configurations and may result in as much as a 20 percent increase for more complex ones. These gains are purely aerodynamic. When the capability is coupled with nonlinear structural analysis capability, a carefully tailored aeroelastic response is possible, giving rise to further improvements of about the same magnitude.

To fully realize such improvements, advanced computational facilities are essential. The Numerical Aerodynamic Simulator that NASA proposes will provide the capability of applying advanced computer algorithms to aircraft and engine design.

Fuels

Continuing research to better understand chemistry, combustion, and emissions of current aircraft fuels has already resulted in more efficient and less polluting aircraft engines. An opportunity and an urgent need exist side by side to build on the existing knowledge by extending it to the wide variety of fuels the United States is almost certain to have to use in the future. Advanced engine and fuel system technology will be required to ensure that engine durability, reliability, efficiency, and emissions are not adversely affected by such fuels.

A better understanding of the stability of the fuels, their physical and chemical properties, their combustion, and their corrosive effects will provide the insights and technological options necessary to deal with the future uncertainties in aviation fuel availability and cost. Such studies should assist the nation significantly in overcoming the uncertainties. In addition, if automobiles are fitted with gas turbine engines, the automotive industry should gain great benefits as well.

High Temperature Materials

The jet engine has been and continues to be a major catalyst in research efforts to extend the temperature ceilings for certain materials. In the past two decades, remarkable progress has been made. The use-temperature of alloys has been increased from approximately 60 percent of the absolute melting point temperature to close to 80 percent. While the advances are remarkable, the melting point constitutes a positive limit, and new types of materials must be sought if significant further advances are to be made.

Refractory ceramics are an obvious choice--though such materials are fragile, brittle, and difficult to form into complex shapes. Research in ceramic materials has been underway for some time. Today, the sources of the brittleness and fragility are reasonably well understood, and the concepts are becoming more clear for designing around the limitations.

While the gestation period for such research is not yet over, the point of applicability is in sight. Further research should result in a revolution in gas turbine engines. Turbine inlet temperatures could be increased by at least 1000° F, and the dreams of thermodynamics

might finally be realized. Future engines could run at stoichiometric conditions, and this would provide a major increase in specific power.

If ceramic components prove successful, the implications for use are very broad beyond aircraft. For instance, stationary power plants using ceramic turbines could generate much more electric power per pound of fuel, as could turbine-driven trains. Ultimately, the technology would diffuse to the chemical, petroleum and metallurgical industries, where greater efficiencies could be obtained.

Composite Materials

Since the early 1920s, materials scientists have recognized that fine filaments or fibers of materials are unusually strong. This observation led to much conjecture about the nature of solids but did not produce any practical applications. About two decades ago, as the need for lightweight, sturdy, durable airframe materials became pressing, both NASA and the Air Force initiated efforts to produce materials with such characteristics by consolidating very strong fibers. After numerous false starts, a class of materials evolved known as "advanced composites". Of this class of materials, graphite fibers embedded in an epoxy matrix proved the most attractive. This material offers the promise of reducing the structural weight of aircraft by as much as 30-40 percent, with a concurrent increase in range and reduction in fuel consumption. NASA undertook demonstrations of the efficacy of such materials by building components and flying them in commercial airline service. As a result of this combined research and technology effort, several thousand pounds of such components are being incorporated into the next generation of commercial transports, and future generations of airliners are expected to be virtually of all-composite construction.

Single Crystal Components

With the turbojet engine came a great need for materials capable of operating at high stresses and temperatures for long periods of time. As a consequence, much basic research in NASA, DOD, and aircraft industry laboratories, as well as in universities, was channeled into understanding the behavior of metals at extremely high temperatures.

It was soon realized that the material near the boundaries between the metal crystals was the weak link and that the elimination of the boundaries would yield a material that withstands higher temperatures. This led to the concept of producing a single crystal turbine blade. At that time, the notion of growing a single crystal turbine blade with internal cooling passages characterized by complex geometry was considered hopelessly difficult. Nevertheless, research continued towards that goal. In a few years, methods for producing blades with very large crystals were demonstrated.

Further research led to the concept of "directionally solidified alloys;" the large crystals of these materials were so aligned that their boundaries were parallel to the principle stresses, and hence were not so fragile. Alloys of this type are in use today.

Finally, the nucleation and kinetics of crystal growth became sufficiently well understood, and the desired intricately shaped, cooled turbine blade was successfully grown. These are operating in experimental engines today, and the facilities are being established for producing the large numbers required.

Over the past 30 years, sustained research on the high temperature behavior of metals and the application of the insights that were gained resulted in an increase of approximately 1000° F in turbine inlet temperatures, with a concommitant increase of 50 percent in thermodynamic efficiency. This has resulted in enormous fuel savings.

Powder Metallurgy

Powder metallurgy became a significant asset for U.S. industry during World War II when it was used to produce components with complex shapes whose strength was not an important consideration. Gears for mechanical calculators, for example, constituted a prime market. Basic research in such materials led to increased understanding of sintering (the process by which powders are fused together), solidification (particularly at very high cooling rates), and strengthening mechanisms in alloys. As the understanding grew, it became evident that high strength, high temperature alloys could be created by powder metallurgy processes and that these would use expensive alloying elements more efficiently than the conventional casting and forging operations then in use.

Further research was required to devise methods to produce very fine, pre-alloyed powders and to process them without deleterious contamination. Such studies conducted in NASA, Air Force, and university laboratories, have resulted in components made from metal powders that meet standard specifications for several jet engines.

Although originally conceived as simply basic studies in metallurgy, these alloys today are conserving strategically critical and expensive alloying elements. In addition, the powders are consolidated to very near final shape, resulting in a large reduction in energy consumption and cost during the final machining operations. This development is expected to have a profound impact on metal processing for a wide variety of applications over the next several years.

Flight Controls

Substantial gains in aircraft performance are possible by using sensors and automatic flight controls to provide stability, relieve loads, and limit the flight envelope. Such control systems are known as active controls. Initially, military aircraft requirements spurred the development of this technology. During the 1960s, the Air Force sponsored several technology programs emphasizing the integration of controls in the configuration design process and coined the term Control Configured Vehicles (CCV). Feasibility demonstrations were conducted for fighter aircraft on the F-16 CCV and for bombers on the B-52 CCV.

The two key research areas vital to the application of active controls are interdisciplinary design theory, particularly structural

dynamics and controls, and development of highly reliable controls. NASA expertise and the Transonic Dynamic Wind Tunnel have been instrumental in developing the theory and testing techniques for active control concepts for wing loads alleviation and flutter control. NASA's long history in theoretical research, analysis, and wind tunnel testing of flutter, as well as its capability in control theory provided an ideal basis for conducting flutter control research. A particularly important theoretical solution to the flutter control program was made by a NASA researcher in conjunction with a university collaborator.

Another important contribution has been the development of a unique wind tunnel testing technique at Langley in which active structural mode controls can be tested on a scaled wind tunnel model. It provides the opportunity to obtain controlled experimental data to compare with theory and has been used in conjunction with the B-52 CCV and C-5A structure-mode-control investigations.

The second key area is highly reliable controls. Relying on the control system to provide static stability or active flutter control requires that the possibility of a system failure be so remote as to effectively ensure that the system will never fail. To achieve this degree of reliability requires significant advances in the electronic portion of the system. Research on digital control systems that could provide the necessary reliability has been underway for over a decade. It was not only necessary to develop redundancy management concepts but also the theory and analysis methods to predict and assess the reliability. New fault tolerant concepts are now being investigated at Langley that could achieve two orders of magnitude improvement in reliability.

Active controls are beginning to appear in operational aircraft. The Air Force's F-16 fighter airplane includes active controls that increase maneuvering and cruise performance by about 10 percent. A derivative version of the Lockheed L-1011 achieves a 4 percent increase in cruise performance as a result of a system to alleviate wing loads. Future applications to transport aircraft have the potential for improving performance by 10 percent or more. Active controls could be very important to rotorcraft in vibration control and ride improvement and will be mandatory for Vertical and/or Short Takeoff and Landing (V/STOL) aircraft.

SPIN-OFFS

NASA research on aeronautical problems results in "spin-offs" to other fields of engineering and science. For example, any progress in the understanding and management of turbulence contributes to the solution of a variety of engineering problems. Similarly, the results on aerodynamic noise pioneered in aeronautical research have been used in problems as diverse as railroad train noise and human heart murmurs. Several specific spin-offs are cited below.

NASTRAN

The NASA Structural Analysis (NASTRAN) program is a computer program for the structural analysis of aircraft and spacecraft. The program has proven to be widely useful in a variety of applications. The automotive industry is using the NASTRAN program to design tire treads for safer tires and to lighten the body and chassis for more fuel efficient cars. Several new consulting companies have been established to provide structural analysis services based on NASTRAN in such diverse activities as the design of high-rise buildings and ships.

Lubricants

Solid film lubricants have been developed for use in jet engines as a back-up lubrication system in the event of failure of the normal liquid lubricants. The most successful of these compounds is molybdenum disulfide. This material has proven useful in a variety of products. Today, there are more than 2000 commercial products on the market in which molybdenum disulfide is used alone or as an additive for lubrication at temperatures as high as 700° F. When used as an additive, it is mixed with conventional lubricants to provide a coating that increases the life of the lubricants.

Composites

As previously noted, composites, particularly those containing graphite fibers, are unusually strong and light materials. While such materials are being incorporated into aircraft, other industries also

are recognizing their potential. In some cases, the industries are making the transition from laboratory to routine production even more rapidly than the aircraft industry. Today, there are tennis racquets, skis, bicycles, and other sports equipment on the market that are made of composite materials. A particularly interesting application is in the field of prosthetics; the weight of such devices as leg braces can be reduced by 75 percent with the use of composites. For the young and very old, the reduction in weight frequently makes the use of these devices possible for the first time.

The automotive industry now is interested in composites. One major automotive company estimates that composites could increase fuel efficiency by 10 miles per gallon with no change in riding quality. What is more, this could be done without a price increase, if production goals are attained.

CONCLUSIONS AND RECOMMENDATIONS

NACA and NASA have made many fundamental research contributions to aeronautics, and this storehouse of advances has been largely responsible for the nation's post-World War II success in aviation. However, there has been an erosion of NASA's research capability, particularly in manpower. This situation, if left unchecked, will surely have major ramifications. The technological capital accrued from past research investments will eventually be depleted. In the process the center of gravity of aeronautical innovation may shift to Europe or Japan.

The expense in dollars and manpower for fundamental research is relatively moderate compared to development projects, and the quality of the personnel is of crucial importance. Moreover, there is a large time frame required to obtain significant results and to see the results affect technology. Thus, it is essential that steps be taken to ensure that the NASA research centers can attract and retain a well-trained and talented research staff. This will require minor changes in the government's personnel policies and a closer cooperation with universities. It also will require the exposure of students to the exciting problems NASA faces. This is of great importance because of NASA's currently low visibility in aeronautics.

Despite the erosion of its research capabilities, NASA has continued to develop state-of-the-art facilities and the associated instrumentation. Efforts must be continued to provide research facilities and techniques that utilize the most recent advances from other fields. The new rapid data acquisition and analysis systems should be exploited to the fullest to enhance wind tunnel productivity and reduce energy use. Since the use of computers in the aircraft design process will greatly aid in reducing design time, the proposed Numerical Aerodynamic Simulator is an essential new facility.

Moreover, the results of aeronautical research have had wide application in other fields, including the development of the technology that made the space age possible. The NACA/NASA bridge from pure research sponsored by a government laboratory to the industrial application of the ensuing technology is unique in the annals of applied research.

REFERENCES

1. Mansfield, E., J. Rapoport, A. Romeo, S. Wagner, and G. Beardsley, "Social and Private Rates of Return from Industrial Innovations." Quarterly Journal of Economics, Volume 91, p. 221, May 1977.

2. Tewksbury, J.G., M.S. Crandall, and W.E. Crane, "Measuring the Social Benefits of Innovations." Science, Volume 209, pp. 658-662, August 8, 1980.

3. Science Indicators, 1976. Report of the National Science Board, National Science Foundation, pp. 4-32, 1977.

APPENDIX A

DEFINITIONS OF ROLES AND DISCIPLINES

To facilitate the task undertaken by the participants in the ASEB workshop, a series of definitions of possible roles for NASA was developed. The roles represent steps in the hierarchy of the research and development process, beginning with a desire for knowledge and an understanding of basic phenomena, an idea, or technical concept, and ending with the design and construction of a vehicle, a vehicle component, or a new operational system.

Definitions of Possible Roles for NASA

Each of the following eight roles as defined by NASA was reviewed by the participants, and the panels considered the extent to which NASA should carry out these roles.

National Facilities and Expertise

This category comprises the development and maintenance of test facilities, including wind tunnels, simulators, and computers, as well as the maintenance of personnel with specialized skills, technical knowledge, and expertise in the field of aeronautics.

Research

Programs in this category are designed to gain basic knowledge and understanding of physical phenomena and processes in all discipline areas relevant to aeronautics. The work is fundamental in character and is performed within NASA, at universities, in industry, and by independent research organizations.

Generic Technology Evolution

This category involves the pursuit of the results of specific lines of basic research that show promise of generating technology broadly applicable to a number of classes of vehicles. The work is evolutionary in nature and leads to the continued advancement of technology.

Such advances generally precede focused technology development in support of specific vehicle class needs. The work is conducted primarily within NASA, with appropriate university and industry support.

Vehicle Class Technology Evolution

NASA programs in this category concentrate on specific vehicle classes and on the preparation of the unique technology data base required to improve the design and development of certain classes of aircraft. Activities include generating and evaluating new concepts and configuration approaches for the vehicle classes. Examples include V/STOL and supersonic cruise vehicles. In both cases, the technologies unique to those classes of aircraft are examined with regard to design feasibility, benefits, costs, etc. Then tailored data bases are developed.

Technology Demonstration

This category includes programs that are conducted to demonstrate the technical feasibility of a technology advance or concept. Activities may include flight testing and component or systems demonstrations. Specific examples in the current NASA program are: Tilt-Rotor Research Aircraft, Energy Efficient Engine, Quiet Short-Haul Research Aircraft, and Terminal Configured Vehicle. Future modifications and tests on an aircraft to demonstrate the feasibility of Laminar Flow Control and flight tests of an Advanced Turboprop would be included in Technology Demonstration.

Technology Validation

This comprises programs that include large-scale ground or flight validation as a necessary step to assure technology transfer. The purpose is to make possible, with minimal risk and without additional technology development, the practical utilization of high-benefit, high-risk conceptual, component, or subsystem technology advances. Specific examples in the present NASA program are: Composite Primary Aircraft Structure (CPAS), Materials for Advanced Turbine Engine (MATE), and Engine Component Improvement (ECI).

Prototype Development

This category consists of design, development, construction, and testing of an aircraft, engine, or system that is sufficiently representative of a planned final product to serve as a production prototype. An example of such a program for the civil sector would be the supersonic transport (SST) program conducted by the FAA during the 1960s. Current NASA programs do not include any prototype developments, and none is currently planned.

Operations Feasibility

This refers to operations conducted as research directed toward evaluating the feasibility or practicality of aircraft system operations to meet special needs or requirements or to demonstrate that a total, integrated operational system (e.g., new aircraft or simulated new aircraft, advanced integrated flight systems, approach and landing techniques, wake vortex alleviation, etc.) provides a service or benefit. The economic, environmental, and/or social aspects are considered.

Definitions of Disciplines

Aerodynamics

Aerodynamics is the science dealing with the motion of air and other gases and with the effects of such motion on objects moving through such media.

Structures and Materials

This is the portion of aeronautical research and technology development dealing with the design of structures (the part of the aircraft, missiles and/or their components whose function is to carry loads in the broadest sense) and the materials used in aircraft and missile construction.

Propulsion

This disciplinary heading includes the part of aeronautical research and technology development relating to the various methods and systems for generating and delivering power for propelling and/or lifting aircraft and missiles.

Electronics and Avionics

Electronics refers to that aircraft and missile electrical equipment that is required for the basic operation of the vehicles--e.g., flight and engine controls. Avionics means the electrical equipment used for mission functions, such as air-to-ground communications and navigation. In military aircraft and missiles, the latter category includes offensive and defensive equipment and weapons control systems.

Vehicle Operations

This area deals directly with operational problems encountered by aircraft and missiles, such as icing, detection and dissemination of weather information, and air traffic control systems.

Human Engineering

This discipline addresses the study of human capabilities and problems that occur at the interfaces between the crew and the aircraft. It includes work on and use of simulators, crew workload studies, and studies of the optimization of cockpit instrumentation and controls.